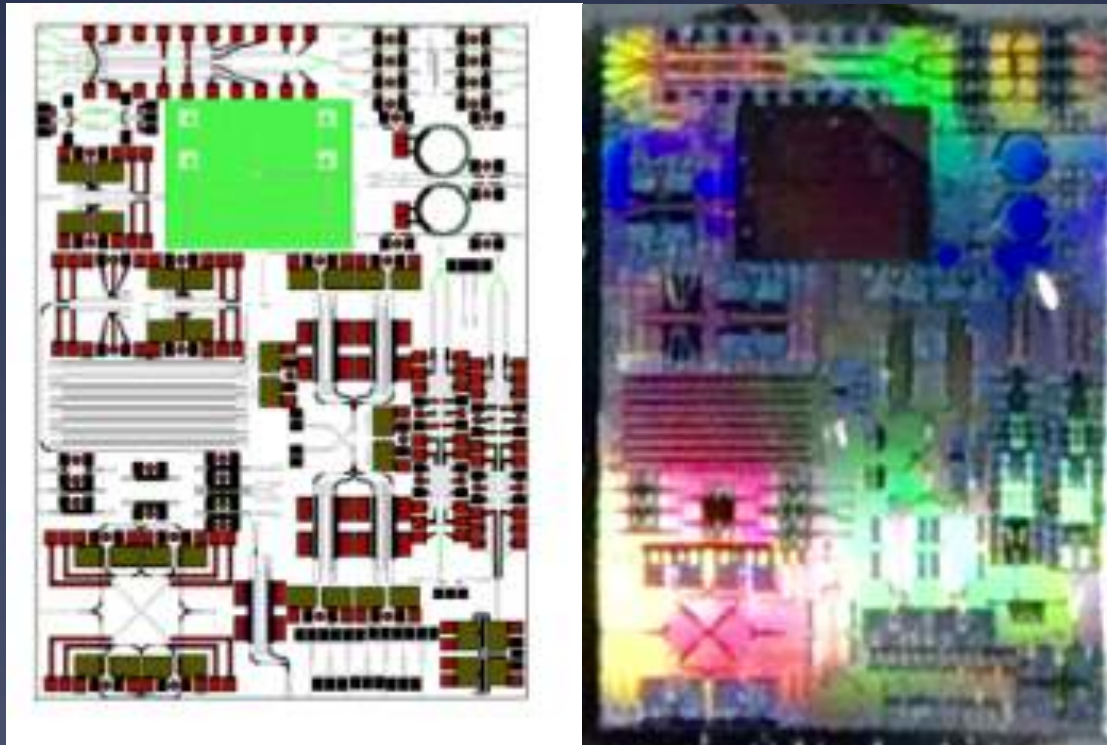




Photonic Integrated Circuits

NASA Goddard Space Flight Center



Michael Krainak, Scott Merritt



AGENDA

- * NASA Application Areas for Integrated Photonics
- * Laser Communication Relay Demonstration (LCRD) modem
- * Photonic Integrated Circuit (PIC) – Examples
- * **Direct-Write** Waveguides, Machining, Patterning, Bonding...
- * Our Early Stage Innovators
- * Acknowledgements



NASA Integrated Photonics



NASA Applications:

- Sensors – Spectrometers - Chemical/biological sensors:
 - ◇ Lab-on-a-chip systems for landers
 - ◇ Astronaut health monitoring
 - ◇ Front-end and back-end for remote sensing instruments including trace gas lidars
 - ◇ Large telescope spectrometers for exoplanets.

- Microwave, Sub-millimeter and Long-Wave Infra-Red photonics:
 - ◇ Opens new methods due to Size, Weight and Power (SWAP) improvements, radio astronomy and THz spectroscopy

- Telecom: inter and intra satellite communications.
 - ◇ Can obtain large leverage from industrial efforts.

LCRD

Laser Communications Relay Demonstration

**Bridging the Gap to the Next
Era of Space Communications**



Ground Station
California

LCRD Mission
Operations Center
White Sands

Ground Station
Hawaii



The diagram illustrates a satellite communication system in space. A satellite labeled 'LCRD LRD 2019' is shown with two large solar panel arrays, one purple and one blue. It has two white parabolic antennas. A red laser beam originates from the satellite and points towards the International Space Station (ISS), which is depicted as a complex structure with multiple solar panel arrays. Another red laser beam originates from the ISS and points towards a ground station on the Earth's surface, located in Africa. The Earth's horizon is visible at the bottom, showing the continents of Africa and Europe. The background is a deep blue space filled with numerous stars. In the top right corner, a small satellite is shown orbiting the Moon, which is partially visible.

**LCRD
LRD 2019**

50 Mbps
Uplink
To ISS

ISS terminal

1.25 Gbps
Downlink
From ISS



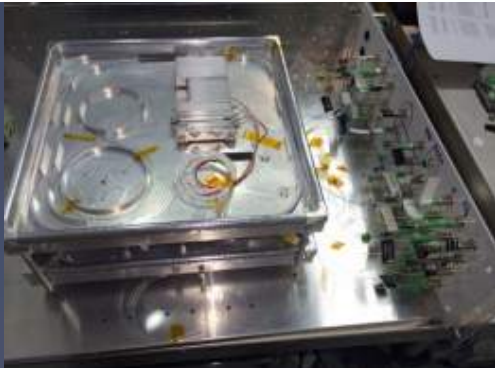
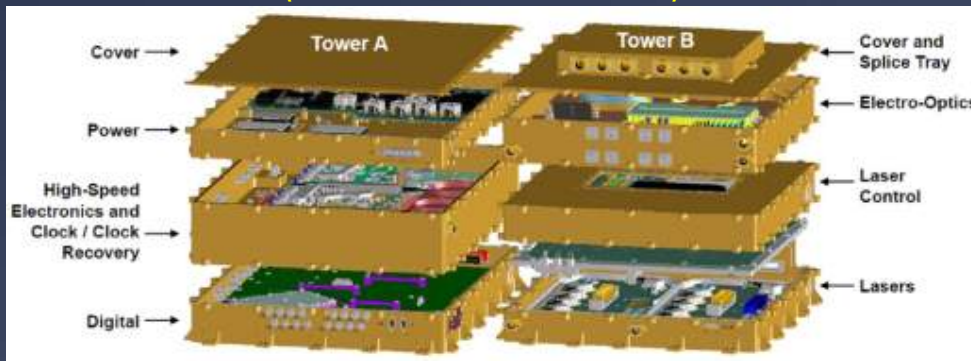
A Vector For Directional Networking



NASA – Space Flight 2019:

- NASA-GSFC: Laser Communication Relay Demo
- Raw rate : 2.5 Gbps Differential Phase Shift Keying
- Developed in-house process for packaging fiber optic system for **LCRD**
- Laser transmitter/receiver for space payload & ground terminal
- Space terminal began fabrication in mid-2015
- Launch Readiness Date (LRD): 2019.

Space Modem (26"L x 6.3"H x 15.5"W)



Terrestrial commercial – Infinera (2014) Deployed in South Africa



5 x 114Gb/s Transmitter

442 Elements: AWG mux, lasers, modulators, detectors, VOAs, control elements

5 x 114Gb/s Receiver

171 Elements: AWG demux, local laser oscillator, 90deg Hybrid, Balanced detectors, control elements

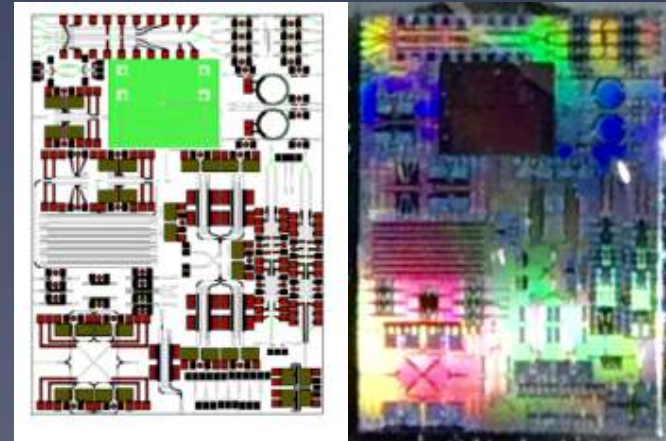
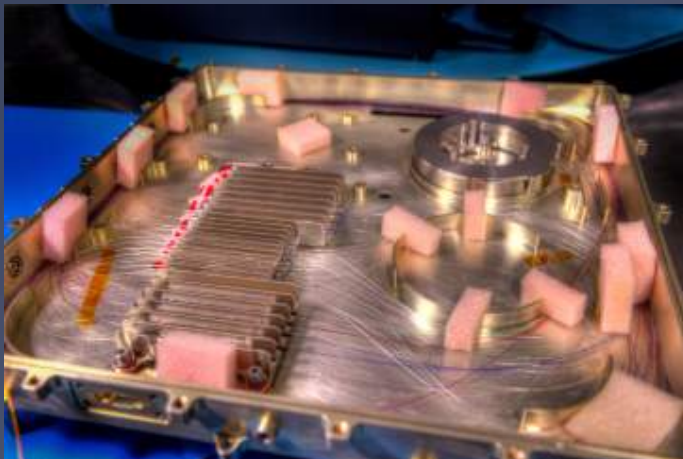


NASA Space Communication and Navigation (SCaN) Integrated LCRD LEO-User Modem and Amplifier (ILLUMA)



Provides pathway to near-Earth low-cost lasercom terminals

- Reduce Size, Weight, and Power (SWAP) plus Cost of spaceflight modems. Use integrated electronics/photronics where cost effective.
- Establish US industrial LEO space-flight modem suppliers compatible with LCRD
- Use vendor up-screened COTS parts where possible.





Transmitter front-end PIC DFB with Integrated MZ modulator (need high extinction ratio ~20 dB) Comparison of integrated InP to LiNbO₃

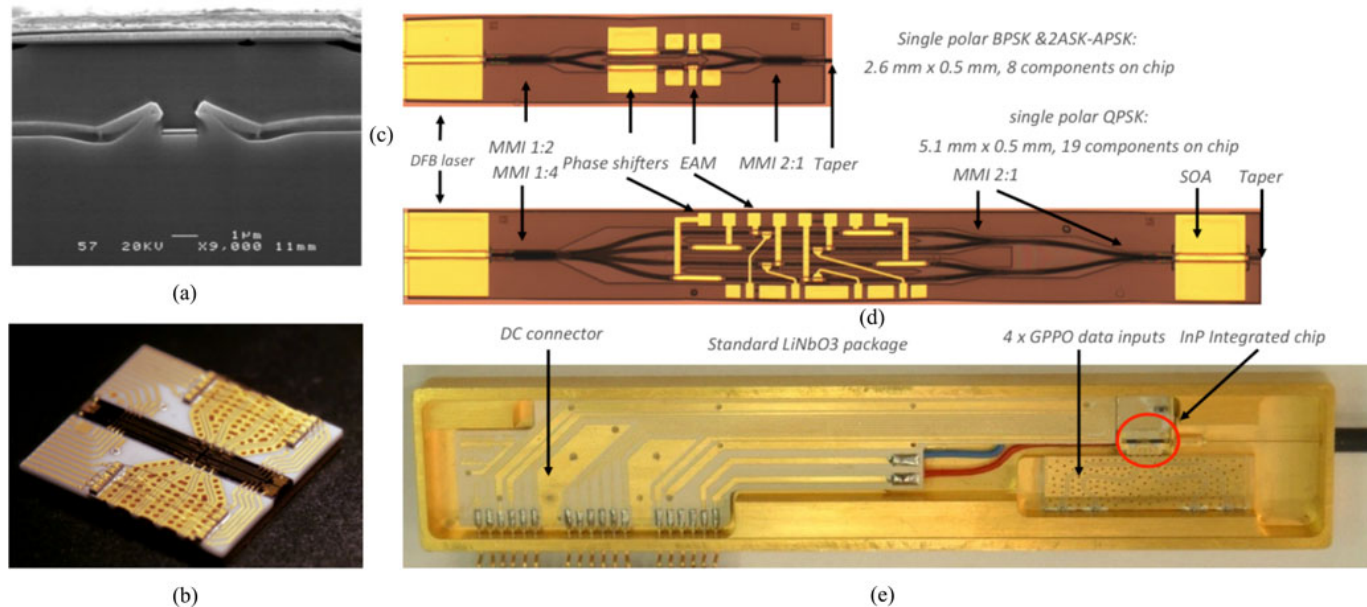


Fig. 2. (a) A cross-view of a SI buried ridge. (b) Transmitter chip mounted on HF submount. Photographs of integrated (c) BPSK & 2ASK-2PSK transmitter,

Monolithic Integrated InP Transmitters Using Switching of Prefixed Optical Phases

Guilhem de Valicourt, Haik Mardoyan, M. A. Mestre, P. Jennev , J. C. Antona, S. Bigo, O. Bertran-Pardo, Christophe Kazmierski, J. Decobert, N. Chimot, and F. Blache



Coherent receiver PIC



6100108

IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL. 20, NO. 4, JULY/AUGUST 2014

Monolithic Silicon Photonic Integrated Circuits for Compact 100⁺Gb/s Coherent Optical Receivers and Transmitters

Po Dong, *Member, IEEE*, Xiang Liu, *Senior Member, IEEE*, S. Chandrasekhar, *Fellow, IEEE*, Lawrence L. Buhl, Ricardo Aroca, and Young-Kai Chen, *Fellow, IEEE*

(Invited Paper)

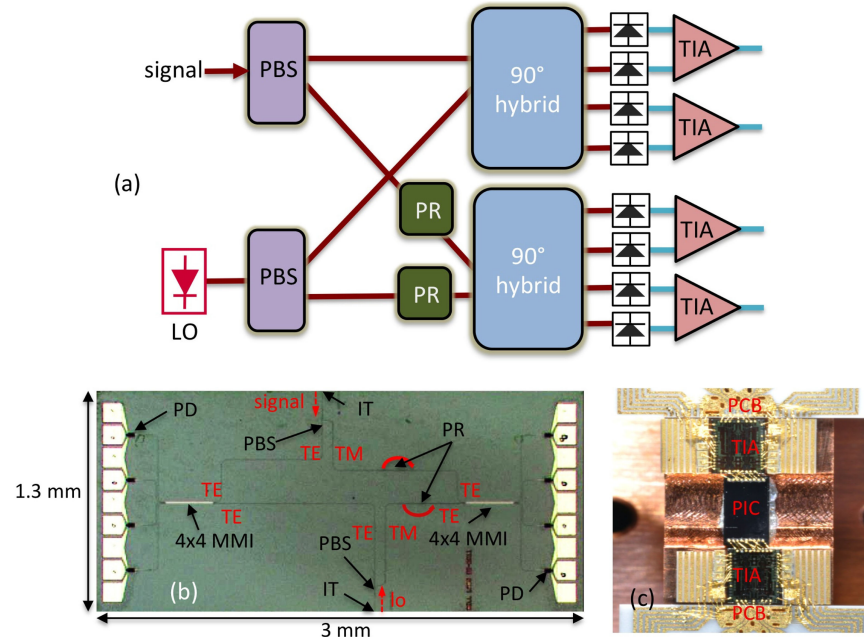


Fig. 3. Polarization-diversity coherent receiver using Si PIC. (a) Photonic circuit diagram. PBS: polarization beam splitter; PR: polarization rotator; TIA: transimpedance amplifier. (b) Photograph of the receiver PIC. PD: photo detector; IT: inverse taper; MMI: multimode interference coupler. (c) Photograph of the packaged coherent receiver. PCB: printed circuit board.



Receiver preamplifier PIC



Erbium-doped spiral amplifiers with 20 dB of net gain on silicon

Sergio A. Vázquez-Córdova,^{1,2,*} Meindert Dijkstra,^{1,2} Edward H. Bernhardt,¹ Feridun Ay,^{1,3} Kerstin Wörhoff,¹ Jennifer L. Herek,² Sonia M. García-Blanco,^{1,2} and Markus Pollnau^{1,4}

¹Integrated Optical MicroSystems Group, MESA + Institute for Nanotechnology, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands

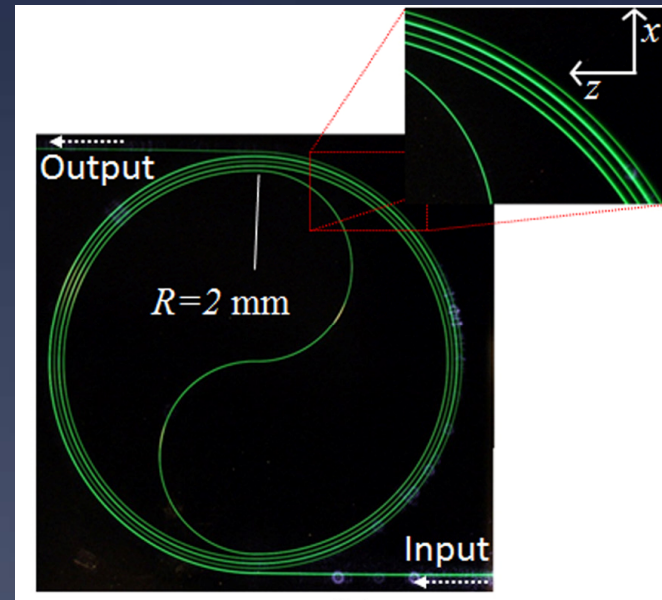
²Optical Sciences Group, MESA + Institute for Nanotechnology, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands

³Department of Electrical and Electronics Engineering, Anadolu University, 26555 Eskişehir, Turkey

⁴Department of Materials and Nano Physics, School of Information and Communication Technology, KTH–Royal Institute of Technology, Electrum 229, Isafjordsgatan 22–24, 16440 Kista, Sweden

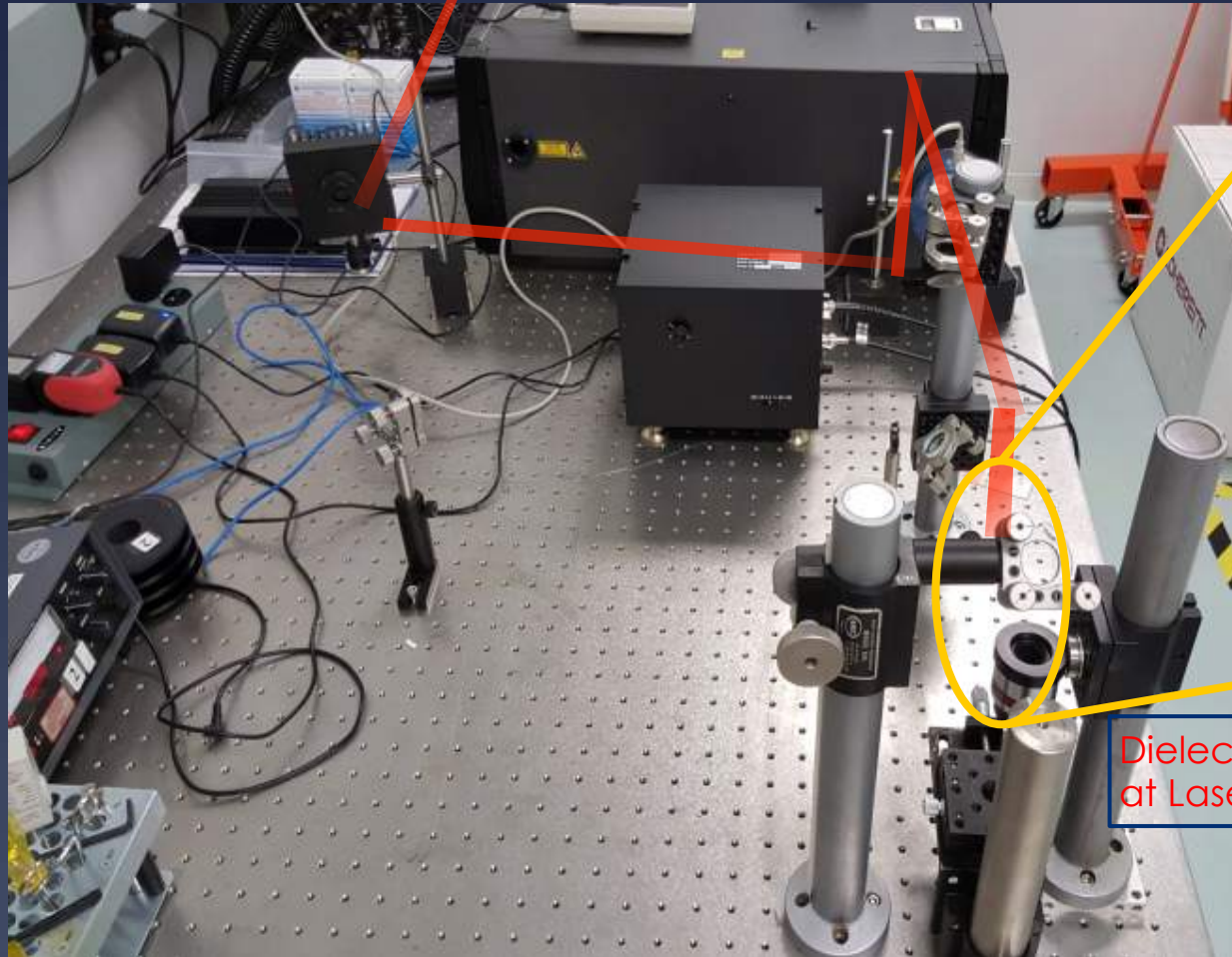
*s.a.vazquezcordova-1@utwente.nl

- Internal net gain = 20 dB
- Noise figure of 3.75 dB small-signal-gain regime.





Goddard Code 554 Femtosecond Direct-Write laser



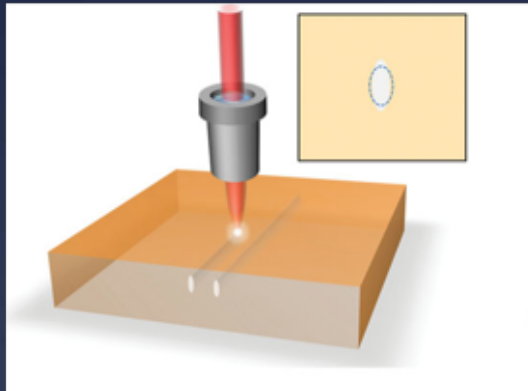
Dielectric Breakdown of Air
at Laser Focus

Fused Silica Witness Sample
Etched by Femtosecond Laser

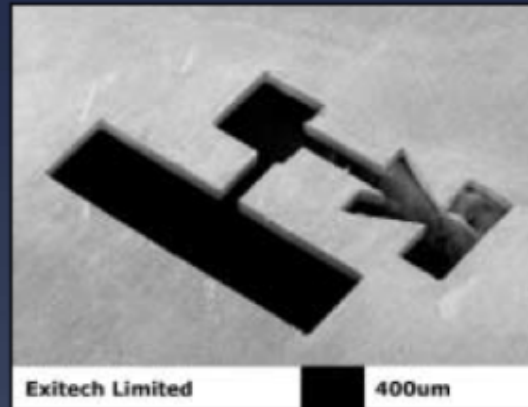




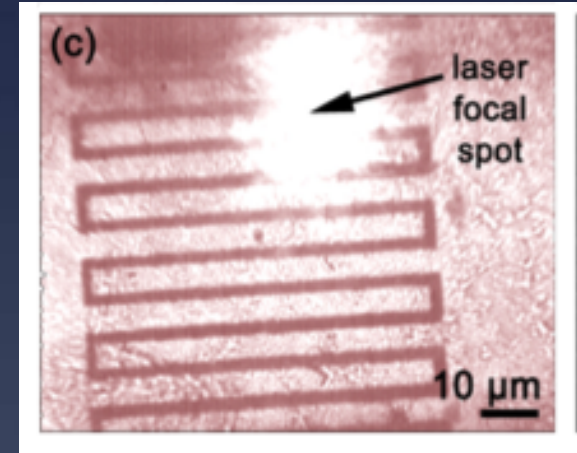
Direct-write laser system is multi-use



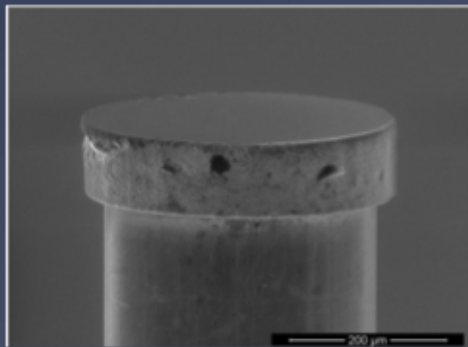
Optical waveguides



Precision Machining



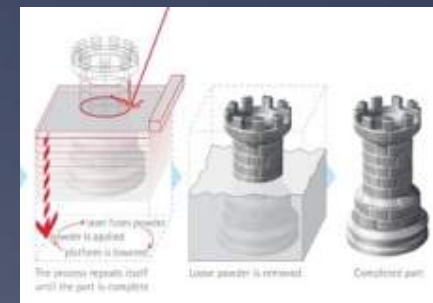
Patterning graphene



Milling/Bonding/welding glass



Glass/copper weld



Additive manufacturing
with laser sintering
(3D printer principle)



Direct write waveguide fabrication

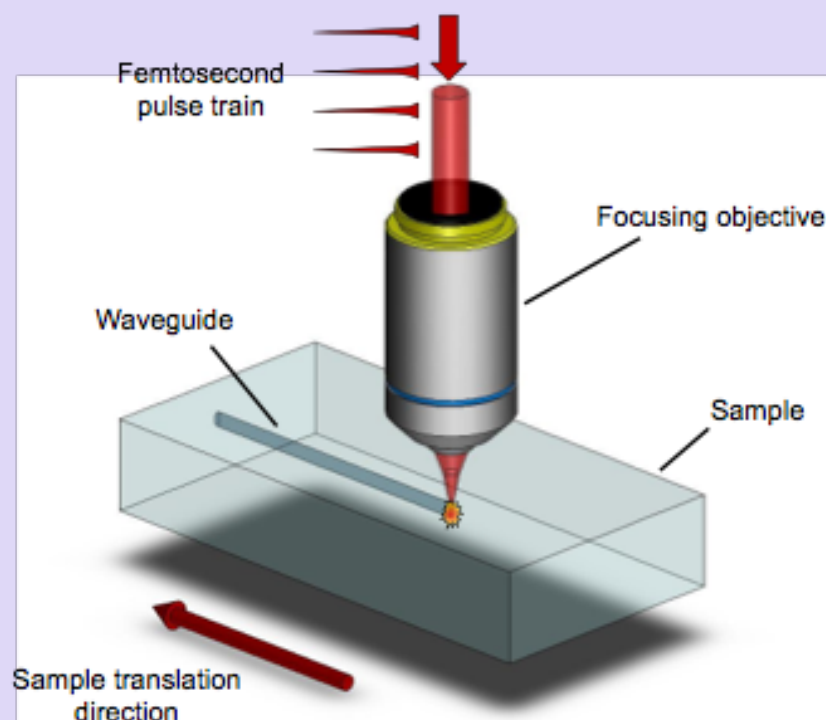


Figure 1. Ultrafast laser inscription setup: A femtosecond laser is tightly focused into the bulk of the sample, nonlinear breakdown occurs, which causes a localized material modification. By translating the sample with respect to the focal spot, arbitrary 3 dimensional structures can be inscribed.



Making lasers with a laser

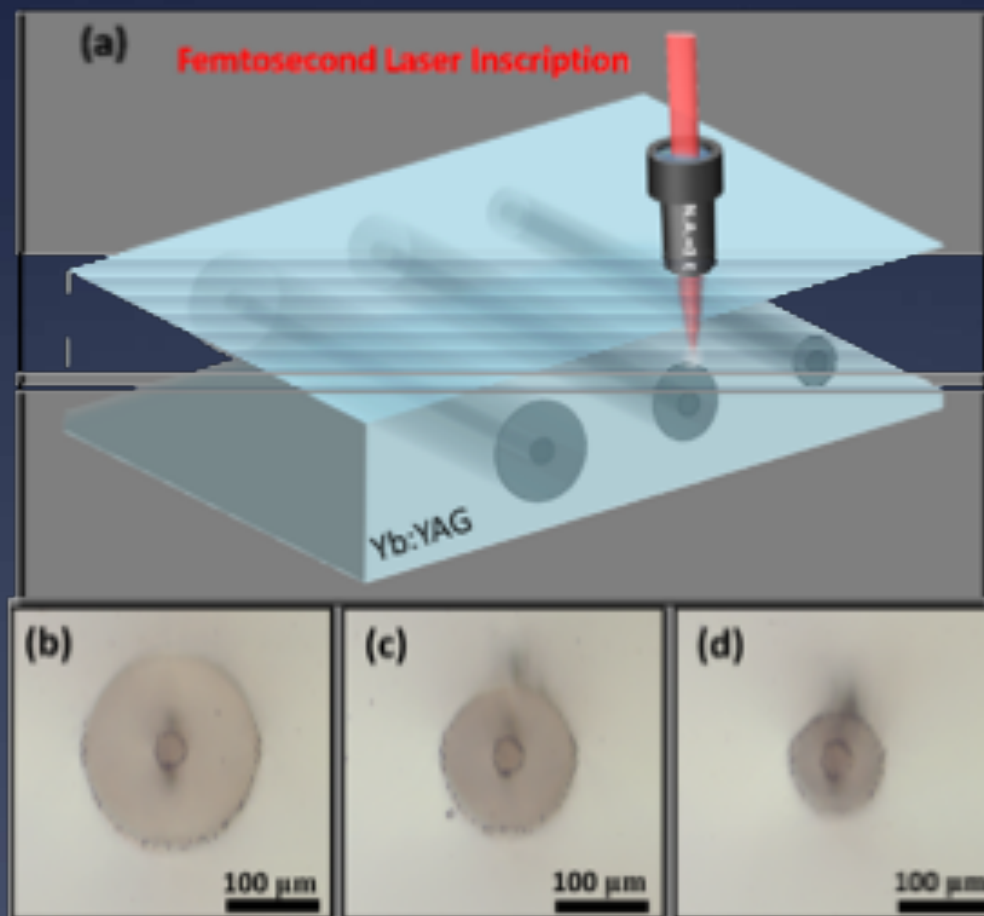


Fig. 1. (a) Schematic of fs-laser inscription process in Yb:YAG ceramics for the double cladding waveguides, and their cross sectional microscope images, which consist of tubular central structures with 30 μm diameter, and concentric larger size tubular claddings with diameters of (b) 200, (c) 150 and (d) 100 μm , respectively.



NASA Space Technology Mission Directorate (STMD)
Early Stage Innovation (ESI)
Integrated Photonics for Space Communication



- * Karen Bergman, Columbia University

Ultra-Low Power CMOS-Compatible Integrated-Photonic Platform for Terabit-Scale Communications

- * Seng-Tiong Ho, Northwestern University

Compact Robust Integrated PPM Laser Transceiver Chip Set with High Sensitivity, Efficiency, and Reconfigurability

- * Jonathan Klamkin, University of California-Santa Barbara,

PICULS: Photonic Integrated Circuits for Ultra-Low size, Weight, and Power

- * Paul Leisher, Rose-Hulman Institute of Technology

Integrated Tapered Active Modulators for High-Efficiency Gbps PPM Laser Transmitter PICs

- * Shayan Mookherjea, University of California-San Diego

Integrated Photonics for Adaptive Discrete Multi-Carrier Space-Based Optical Communication and Ranging



Acknowledgments



NASA STMD

NASA SCaN

DoD IP-IMI

AETD colloquium

Thank you!

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